EVALUATION OF WATERFLOODING USING CARBONATED WATER FOR OIL RECOVERY

MOHAMAD FAIZUL BIN MAT ALI

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This thesis is dedicated to:

My wife Noraini binti Ibrahim

My family especially for my late mother Adima binti Lin

And last but not least for my future kids

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ABSTRACT

Malaysian oilfields especially in Malay basin are showing the signs of maturity phase that involves high water-cut and pressure declining, after more than 30 years of extensive exploration and production. In recent development, Malaysia underwent Water Alternating Gas (WAG) process in the Tapis field to improve oil recovery. However, WAG, which utilises carbon dioxide in the Enhanced Oil Recovery (EOR) process has a few flaws that includes poor sweep efficiency due to high mobility ratio of gas and oil, which promotes an early breakthrough. Therefore, a concept of carbonated water injection (CWI) to utilise carbon dioxide was applied. The aim of this study was to measure the suitability of carbonated water to be implemented in oil recovery at high pressure condition, simulating reservoir condition. The simulated reservoir condition was made using a coiled sand pack filled with rounded grain glass beads and pressurised to 2000 psi with 60 °C as a controlled condition. A series of displacement test to investigate the range of recovery improvement at different carbon dioxide concentrations were carried out using different recovery mode stages. Wettability analysis has also been done to analyse the wettability of sandpack treated with carbonated water. The result from this study has shown a positive improvement in oil recovery with 50% concentration of carbon dioxide showed the highest recovery where it recovered additional 28% oil in secondary recovery and 16% recovery in tertiary recovery. Carbonated water also has the ability to alter the wettability of sandpack and sandstone rock to become more water-wet condition. Moreover, carbonated water was more suitable to be in the secondary recovery process, replacing the plain waterflood process, which is a common practice in every field. As a conclusion, carbonated water has a high potential in oil recovery processes, in both secondary and tertiary stages.

ABSTRAK

Lapangan minyak di Malaysia terutama sekali di Lembangan Melayu telah menunjukkan fasa kematangan, misalnya nisbah air yang tinggi dan juga pengurangan tekanan. Dalam perkembangan terbaharu, Malaysia telah mula menjalankan projek Perolehan Minyak Tertingkat di lapangan minyak Tapis yang menggunakan cara suntikan selangan air dan gas. Namun begitu, aplikasi ini mempunyai beberapa kelemahan, antaranya perolehan yang rendah disebabkan oleh nisbah mobiliti gas dan minyak yang tinggi menyebabkan perlepasan gas pramatang. Oleh itu, konsep suntikan air berkarbonat digunakan untuk mengatasi masalah ini. Kajian ini dilakukan bertujuan untuk menilai kesesuaian cara suntikan air berkarbonat untuk diaplikasikan pada keadaan tekanan tinggi sesuai dengan keadaan reservoir minyak. Model reservoir minyak telah dibina dengan menggunakan padatan pasir pada tekanan 2000 psi dan suhu 60 °C. Beberapa siri ujian sesaran pada kepekatan karbon dioksida yang berbeza telah dilaksanakan bagi menyiasat julat keupayaan perolehan minyak pada peringkat perolehan yang berbeza. Analisis kebolehbasahan suntikan air berkarbonat juga telah dijalankan bagi mengenal pasti keterbasahan padatan pasir dan batu pasir yang digunakan dalam kajian. Hasil kajian menunjukkan bahawa air berkarbonat dengan ketepuan 50% telah menghasilkan perolehan minyak yang tertinggi dengan tambahan perolehan sebanyak 28% menerusi perolehan Sekunder dan 16% menerusi perolehan Tertier. Kajian ini juga mendapati bahawa air berkarbonat mempunyai kebolehan untuk meningkatkan lagi keterbasahan mampatan pasir dan batu pasir. Selain itu air berkarbonat adalah lebih sesuai digunakan pada proses perolehan Sekunder bagi menggantikan proses banjiran air yang digunakan selama ini. Sebagai rumusan, suntikan air berkarbonat didapati mempunyai potensi yang baik dalam proses perolehan minyak yang mencakupi kedua-dua perolehan Sekunder dan perolehan Tertier.

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LIST OF ABBREVIATIONS

ASP	-	Alkali Surfactant Polymer
BPD	-	Barrel Per Day
BSTB	-	Billion Stock Tank Barrels
BT	-	Water Breakthrough
CWI	-	Carbonated Water Injection
EOR	-	Enhanced Oil Recovery
IFT	-	Interfacial Tension
MEOR	-	Microbial Enhanced Oil Recovery
MMP	-	Minimum Miscibility Pressure
OOIP	-	Original Oil In Place
PGAW	-	Polymer Gas Alternate Water
PV	-	Pore Volume
SAGD	-	Steam Assisted Gravity Drainage
STOIIP	-	Stock Tank Oil Initially in Place
$SWACO_2$	-	Simultaneous Water-Carbon Dioxide
$WACO_2$	-	Water Alternating Carbon Dioxide
WAG	-	Water Alternating Gas
WF	-	Waterflooding

NOMENCLATURE

°API	-	Degree API of Oil
°C	-	Degree Celsius
ϕ	-	Porosity
$\Delta P/L$	-	Pressure Gradient
μ_0	-	Oil Viscosity, cp
λ_g	-	Gas Mobility, md/cp
λ_o	-	Oil Mobility, md/cp
λ_w	-	Water Mobility, md/cp
ρ_o	-	Oil Density, g/cc
ρ_w	-	Water Density, g/cc
γ	-	Specific Gravity
A	-	Cross sectional Area, ft^2
cc	-	Cubic Centimeter
cp	-	Centipoise
ft	-	feet
g	-	Gravity Acceleration, m/s^2
ID	-	Internal Diameter, in
K	-	Permeability, md
K_{abs}	-	Absolute Permeability, md
K_g	-	Effective Gas Permeability, md
K_o	-	Effective Oil Permeability, md
K_w	-	Effective Water Permeability, md
K_{rg}	-	Relative Gas Permeability
K_{ro}	-	Relative Oil Permeability

K_{rw}	-	Relative Water Permeability
L	-	Length, ft
M	-	Mobility Ratio
MW	-	Molecular Weight, lb/mol
OD	-	Outer Diameter, in
psi	-	Pressure, pound per square inch
T	-	Reservoir Temperature, ^{o}C
V_b	-	Bulk Volume, cc
V_p	-	Pore Volume, cc

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CHAPTER 1

INTRODUCTION

1.1 Research Background

Recent trend in Malaysia has shown a promising future for Enhanced Oil Recovery (EOR) technology with the latest occurrence of Tapis EOR project. Tapis EOR project, which started in 2014, will become the first EOR project that will be done in Malaysia. Tapis field will be implementing Water Alternating Gas - Enhanced Oil Recovery(WAG-EOR) method for recovering unexpended oil, which uses Carbon Dioxide (CO_2) as the alternating gas. Generally, CO_2 gas was being used in this process since CO_2 gas is highly soluble in oil (Nasehi and Asghari, 2010). Furthermore, CO_2 gas is readily accessible in excess amount, thus, this will reduces the cost for obtaining CO_2.

However, the utilisation of CO_2 gas in EOR as injection technology has a shortcoming. It has been widely known that the implementation of CO_2 gas in EOR technology will face one major dilemma, which is premature breach of gas (Riazi *et al.*, 2009). Thus, maintaining a small early breakthrough will become the number one task when applying gases into EOR process. This will also become the problem that will be tackled when Tapis WAG-EOR process begins.

In recent years, CO_2 gas has become an increasingly popular research area in EOR technology. The application of CO_2 gas in EOR technology has been utilised all around the world. Research in improving CO_2 technology has been showing much improvements toward the application of CO_2 gas in EOR project (Dong *et al.*, 2011a). One of the improvements that have been arising from CO_2 technology problem was the application of carbonated water (Dong *et al.*, 2011b). This technology has been manipulating the ability of CO_2 to miscible with oil and water to enhance oil production especially in the EOR process.

This recent development should be taken into account in dealing with CO_2 project. Studies should be carried out to investigate the suitability of carbonated water as a new option in EOR especially for the future Malaysia EOR project. Laboratory scale research should be designed and carried out in order to evaluate carbonated water for future application. This will enables us to further understand the effect of carbonated water towards oil recovery improvement.

1.2 Problem Statement

One of the major problems in gas especially CO_2-EOR project is the early CO_2 breakthrough due to channelling of CO_2 via reservoir fluids. The channelling of CO_2 in reservoir fluid was due to the properties of gas that travels in the easy path of reservoir structure. This behaviour will caused fingering effects that eventually produce poor sweep efficiency. Several strategies have been introduced including Carbonated Water Injection (CWI) in improving injection performance compared to other conventional CO_2 injection (Sohrabi *et al.*, 2011). CWI method had gained respect as an economically convenient way of augmenting hydrocarbon production. Hence, it is essential to understand the property changes during CWI to optimise the efficiency of the process as well as maximising oil production.

Improvement in sweep efficiency of gas injection process has become one of the objectives in EOR study. It was known that gas injection has major problems associated with it such as the early breakthrough due to fingering. Fingering effect has caused shorter contact time with targeted crude oil in the reservoirs. This was also common when using CO_2 injection process, which resulted in poor areal sweeps efficiency that leads to an early breakthrough.

The next improvement that should be highlighted is the wettability changes in CWI. Wettability of reservoir rock is one of the parameters that control the remaining oil-in-place. Thus, the understanding of wettability changes during displacement process is an important subject in the displacement study for recovering oil efficiently. Hence, a study focusing on the wettability change of carbonated water towards reservoir rock will be carried out.

Last but not least, a suitable stage in introducing carbonated water into reservoir also plays an important role in EOR. Some researchers have suggested an application of carbonated water in secondary recovery (Asghari *et al.*, 2009) while others have proposed carbonated water as a method in tertiary recovery stage (Kechut *et al.*, 2010). Since carbonated water will be applying the same concept of waterflooding process, thus, a clear line on implementation stages should be addressed so the recovery of residual oil can be improved.

1.3 Objectives

Based on this research, the objectives of this study are:

1. To investigate the effect of CO_2 concentration in carbonated water towards oil recovery.
2. To evaluate the wettability behaviour of sandstone rock by measuring water-advancing contact angle in different rock-water-oil systems using sessile drop method at different CO_2 concentrations of carbonated water.

3. To compare oil recovery obtained by injecting the carbonated water to sandpack with that obtained by implementing secondary stage recovery and tertiary stage recovery.

1.4 Scope and Limitation of Research

This research concentrates on investigating the potential of carbonated water as an EOR method that could be used in Malaysian oilfields. Throughout the study, the temperature and pressure are constantly at 60 °C and 1000-2000 psi, respectively. The temperature was chosen as to assimilate the condition of the Malay Basin, which has a geothermal gradient of 5 °C /328 ft (Tjia and Liew, 1996). The pressure was chosen to simulate oilfield pressure, which has a depth of 4000-6300 ft. All results in this research are only applicable on the condition that has been set during the study.

For the purpose of this study, a salinity of simulated connate water of 10,000 ppm has been chosen throughout this study. Simulated reservoir was made using 60ft coiled sandpacks with 1.86×10^{-3} ft in outer diameter (OD) and 1.54×10^{-3} ft in inner diameter (ID). The cross-sectional area is 0.00027 ft^2 and the bulk volume of sand pack is 458.8 cc. Meanwhile, the pore volume is about 160.58 cc with porosity of sand pack approximately 35 percent. The absolute permeability of the sand pack is approximately 7.789 Darcy. The tube was packed with 80-100 mesh rounded grains glass beads to represent fine grained sandstone reservoir rock porous media. Crude oil used was obtained from kemaman crude oil terminal with oil viscosity of 3.67 cp and density of about 0.8264 g/cc (41°API). The injection rate for all runs was set constant throughout the study, which is 560 cc/hr.

Wettability analysis was done in room condition since there was no suitable equipment that can be used to determine the contact angle in reservoir conditions. A set of carbonated water was prepared in high pressure condition and then the pressure was gradually decreased until it reached room conditions. The test was conducted using a sessile drop method, which is a direct contact angle measurement to determine the contact angle of oil and water, consequently determining the wetting phase of reservoir sandstone rock model. The experiment was repeated several times to improve reproducibility.

1.5 Significance of Study

The accomplishment of this research would greatly contribute in the research community. The outcome of this research will provides a further insight into the carbonated water process. Good comprehension on carbonated water was needed so that we can improve our approach on carbonated water and enable us to add more information in improving oil recovery using carbonated water. Extensive research on carbonated water will improved the probability on carbonated water into a full scale real field application in a near future.

Based on this research, carbonated water has its additional values in improving residual oil recovery. Carbonated water injection (CWI) can become an alternative injection strategy that eliminates many of the shortcomings of direct CO_2 injection. Carbonated water has a much better sweep efficiency, as its viscosity is higher than that of water and much higher than that of CO_2. In terms of CO_2 storage, CWI provides one of the safest mechanisms for CO_2 storage, since the injected CO_2 is in solution rather than free phase. CW has higher density compared to water and hence it sinks in the reservoir as opposed to bulk CO_2 injection where CO_2 floats under the caprock representing significant leakage risks.

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